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SYNOPSIS OF INFORMATION ON RADIOACTIVE ELEMENTS IN SEA WATER AND IN THE MARINE FOOD CHAIN

Prepared by

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PURPOSE OF THIS SERIES

This is one of a series of synopses of information on the methods and subjects of fisheries biological research. The primary purpose of this series is to make existing information readily available to fisheries scientists, and by so doing also to draw attention to gaps in knowledge, and provide background material for designing research programs.

The synopses are the output of a system for cumulative storage and retrieval of data called Methods and Subjects Thesaurus (MAST) maintained by the Fisheries Biology Branch of FAO. They will be brought up to date from time to time as further information becomes available.

PREPARATION OF THIS SYNOPSIS

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Synopsis of information on radioactive elements in sea water and in the marine food chain.

Review of data on natural background radioactivity in the sea, possible fate of artificial radioactive substances and on uptake, accumulation and loss of radioactive substances by various links in the marine food chain; bibliography.

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1. NATURAL RADIOACTIVITY OF THE SEA AND ITS BIOTA (background radiation)

Natural radioactivity in sea water occurs mainly in radiopotassium (K-40). The rest of the radioactive elements in sea water (Rb-87, U-238, Ra-226, C-14, U-235, and Th-232) contribute slightly more than 10 per cent of the natural radioactivity. This natural radioactivity of sea water is about 1/10th of the natural radioactivity of granite rocks.

Further contribution to radioactivity in the water comes from cosmic radiation, which, however, is absorbed quickly by the uppermost layers of the sea. Of the ca 35 mrad of the cosmic radiation coming to the surface, only ca 30 per cent reaches a depth of 10 meters and 4 per cent a depth of 50 meters.

The radioactivity of the sea bed varies with the type of sediment. Highest activities are found in deep water sediments, highest in red clay, followed by blue clays and calcareous (e.g. globigerina) oozes. The radioactivity of shallow water sediments with which commercial marine food resources may come into contact, have considerably lower natural radioactivity than the average soil on land, or about 1/3rd of the natural radioactivity of granite rocks.

Marine animals living in the sea also receive, besides the external radiation described above, some radiation from internal sources, mainly from radiopotassium accumulated in the bones. The differences between the radiations received by man on a granite rock at sea level and pelagic (surface dwelling) large fish in the sea (in a depth of ca 20 m), can be demonstrated with the following data (Folsom and Harley 1957, modified).

Man

Cosmic rays 35, + granite 90 + internal 17 = 142 mrad/year

Fish (pelagic)

Cosmic ray 5 + Sea water 1 + internal 28 = 34 mrad/year

2. PRESENT AND NEAR FUTURE SOURCES OF ARTIFICIAL RADIOACTIVITY IN THE SEA

Man is concerned with the artificial radioactivity in the sea mainly a) as it might affect his health through consumption of sea food, b) it might affect the ecological balance of marine resources and c) it can be used for the study of physical-chemical and biological processes in the sea.

There are at present several different groups of sources of artificial radiation to the sea which produce radioactive wastes with very different composition and level of activity.

Ore treatment and refining produces low level wastes which contain mainly uranium and daughter products. The main types of ore wastes are: wash waters, wash solids and process liquids, derived from chemical recovery and enrichment. These wastes usually reach the sea with runoff (rivers).

The earlier reactors, where primary coolant was taken from natural waters and passed back to natural water bodies, induced radioactivity, and radioactive corrosion products were the main sources of radioactivity released into these waters. In modern reactors the primary coolant is in a closed system. In this system, radioactive impurities can enter the natural water only if there is a leak between the primary and secondary cooling systems. However, the primary coolants are usually passed through ion exchangers. These ion exchangers, usually contain medium activities and are usually disposed of in land areas.

Major amounts of radioactive waste arise from spent fuel elements and their chemical processing. More than 99.9 per cent of these fission product wastes are high active, and are disposed of in land areas. We will not deal in this summary with these high-active wastes. However, it can be mentioned that it might be possible in the future to dispose of these wastes in the deep sea, if a technical method can be developed to cast these hot wastes into porcelain or glass. The development of heat and gases by the highly active wastes, however, prevents at present the satisfactory casting of these wastes into the glass. However, the leaking rate of glasses in sea water is very slow. The development of heat would be compensated by convective cooling in the deep sea and might even cause favourable effect, mixing deep water (which is warmed by the heat produced by the waste), with surface waters and thereby bring the nutrient rich deep water into the photosynthetic zone. The irradiated fuel treatment plants also produce quantities of low and medium level effluent waste, which in many cases are released, after certain dilution and purification processes, into natural water.

The use of radioactive isotopes in various fields of scientific research as well as in medicine produces liquid and solid radioactive wastes of predominantly medium and low activity. Low activity effluent wastes are usually disposed of after dilution, in sewers, and the solid wastes are packaged and disposed of in land areas or in the sea.

With the use of nuclear reactors in ships, wastes will be produced directly at sea. By the present construction of ships' reactors, the main types of radioactive wastes are: the excess volume of coolant by warm up which usually must be displaced at start by commercial vessels. The

bulk of radioactive wastes will be contained in the ion exchange resins, which must be disposed of periodically, and various laboratory effluents and equipments and decontamination wastes arising from the operation.

At present, radioactive elements arise also from the test of nuclear weapons. These elements come into the sea immediately from the test seats in the sea, as fallout from atmosphere, or, are washed from land surfaces with runoff.

3. FATE OF ARTIFICIAL RADIOACTIVE SUBSTANCES IN THE SEA

Artificial radioactive elements are released into the water either as particulate matter or as dissolved substances.

The particulate matter can either float or sink. It can also be dissolved and it can be taken up by marine animals with food. The sinking (sedimentation) speed depends on the specific gravity of the particles, their size and turbulence in the sea. Ultimately, most of the particulate radioactive matter will sink to the bottom where it causes a higher activity in the surface layer of the sediment.

Dissolved substances, which undergo dilution by different mixing processes in the sea, might enter into chemical reactions with other dissolved substances, they might be precipitated or might be absorbed and/or adsorbed by suspended matter, both living and dead and settle together with it to the bottom. In practice the most important aspect of the fate of radioactive substances in the water is the reconcentration of these substances by aquatic plants and animals and the accumulation of these substances in aquatic food sources. The data available on this problem will be summarized in greater detail in Chapter 4.

4. UPTAKE, ACCUMULATION AND LOSS OF RADIOACTIVE SUBSTANCES BY MARINE BIOSPHERE

Marine organisms are taking up elements either directly from the water or through the food chains. There is also certain absorption and adsorption of substances by the body surface, gills etc. The rate of uptake, accumulation and loss of elements depends on the type of organisms and their living and feeding habits, physiology, age of the organisms and on the specific environment where the organisms live. There is also a selectivity in the uptake of the elements depending mainly on the physiological function of the element in the organisms. Therefore, the different ecological groups are treated separately below. It could be mentioned that our knowledge of the behaviour of individual radioactive isotopes is still rather limited. However, a considerable amount of information on the behaviour of isotopes in the marine environment can be obtained from the behaviour and distribution of corresponding non-active isotopes.

4.1 Marine bacteria

Marine bacteria are mainly associated with particulate matter in the sea. One of their important functions is the decomposition of organic matter. Besides taking up the elements from the decomposible organic matter, they can also take up elements rapidly from sea water directly, either by absorption or adsorption. However, the bacteria are decomposed rapidly upon death and the substances contained in the soils are released back into the sea. As the increase and decrease of bacteria populations in the sea is rapid, they can cause rapid changes in the content of radioactive substances in solution (e.g. after the phytoplankton bloom, high standing crop of bacteria can take up much activity, but will release it shortly after the death and decay of the plankton detritus).

No actual data are known on the speed of uptake or on the concentration factors of the radioactive isotopes by bacteria. It is worth mentioning that it has been assumed that marine bacteria are the main producers of vitamin B-12 and therefore could accumulate Co-60 from sea water in high concentrations. This vitamin is passed further to other marine organisms.

4.2 Phytoplankton and seaweeds

Phytoplankton and seaweeds concentrate the radioactive elements at highest rate and a greater number of isotopes may be taken up by them than by other biological groups.

Seaweeds can be used directly as human food, as fertilizers or as raw materials for chemicals. Therefore, the maximum quantities used by small groups of individuals and the concentration of radioactive isotopes in them may determine the maximum rate of disposal of radioactive wastes in many localities. Some concentration ratios are given in Table 1. The uptake of elements varies with the growing season of the weeds and is maximum at the time of intensive growth. The uptake is more intensive and rapid in the light than in the darkness (e.g. more rapid in the surface layers than in deep water).

Phytoplankton is not used directly as human food. However, it is consumed by zooplankton, by some filter-feeding fish and by benthic animals. Because of the high concentration rate of radioactive isotopes by phytoplankton, it can serve as a general indicator of the levels of introduced radioactivity in the sea.

The quantities of phytoplankton vary by location and season. Upon death, phytoplankton is decomposed rather rapidly and the chemical elements released back into the water. Speed of regeneration depends greatly on temperature. A small fraction of phytoplankton is sedimentized to the bottom in shallow water.

There are great difficulties in establishing exact mathematical formulae for computation of concentrations and transport of radioactive isotopes, by marine organisms, because many biological processes cannot be predicted quantitatively and there are countless factors influencing the biological processes. Some mathematical models, however, are given by several workers for computation of the rates of uptake of radioactive isotopes (Mac Robbie and Dainty, 1958; Aten, 1958; Ketchum and Bowen, 1958). The main approach to these problems remain the estimations, using experimental data.

The following examples from literature will illustrate the varying and rapid rate of uptake of radioactive substances by plankton.

Saito and Samashima (1956) found that equilibrium between algae water was established in four hours and after 24 hours about 75 per cent of the radioactivity was found in algae. On the other hand, the removal of the isotopes from the algae was slow. After three weeks about 70 per cent was removed. Pendleton and Hanson (1958) found that the ecological system as a whole, including inorganic surfaces, removed 95 per cent of the introduced radioactive contamination from the water in 50 hours and 99 per cent in five days.

Among the characteristics of phytoplankton and plankton in general in respect of uptake and concentration of radioactive isotopes, the following have been reported:

Plankton appears to be the most sensitive indicator of radioactivity in the sea (Seymour et al 1957) and it has at the present measurable artificial gamma activities in many parts of the oceans (Folsom and Hori - MS). Donaldson et al (1956) and Seymour et al (1957) found during the surveys of radioactivity in the sea near Bikini and Eniwetok atolls and Marshall Islands area long after the weapon tests that the average value of the radioactivity in plankton was about 7,100 and 2,500 times the average value for surface water in the respective areas.

Krumholz, Goldberg and Borough (1957) noted that the uptake of radioisotopes depends greatly on the concentration of the element in the environment. Rice and Willis (1959) found that different species of algae concentrated cerium-144 from 300 to 3,000 times over the amounts in the medium in a period of 30 minutes, and after 24 hours all species had concentrations 2,000 to 4,500 times that of the water. Cerium-144 was also taken up by phytoplankton during three days in darkness. Particulate cerium-144 became associated with the algae faster than the ionic cerium. Twenty-five per cent of the cerium-144 was lost in five hours when the cells of phytoplankton were suspended in isotope-free sea water. By each cell division half of the cerium-144 content of individual cells was lost in isotope-free water ("biological dilution"). Chipman, Rice and Price (1959) found that diatoms take up Zn-65 quickly from the medium but very little of it leaves the cells when suspended in non-active water.

Differences of uptake accumulation and loss of individual isotopes by different phytoplankton species were also noted by Borough, Chipman and Rice (1957) who found great variations in strontium/yttrium ratios in different species. Furthermore, they found that cesium-137 is concentrated only by the factor of 1.2 to 3.1.

4.3 Zooplankton

Zooplankton uses phytoplankton as food and takes up radioactive isotopes through this food chain. Elements are also absorbed directly from the sea water by zooplankton and a rapid uptake of elements in particulate form has also been observed. There is a certain selectivity in the uptake of the elements as several of them are disseminated by digestion and metabolism.

Some zooplankton organisms are used as human food (e.g. squids) in certain areas.

Plankton has limited mobility and is carried around in the sea by currents. However, through sinking (or occasionally by rising to the surface) it can carry elements into the deeper layers (or up to the surface). Many zooplankton organisms have diurnal migrations from the deeper layer to the surface layer, or from the deeper layer to the discontinuity layer, and can transport elements by these migrations. There are also large seasonal migrations for spawning purposes from the deeper layer to the surface (e.g. from below 2,000 m).

Few data are available on the uptake and accumulation of radioactive isotopes by zooplankton. Borough, Chipman and Rice (1959) report that Artemia reached a steady state in a few hours. Folsom and Hori (MS) found that relatively high activities are usually found in filter feeders. Furthermore, Krumholz, Goldberg and Borough (1957), stated that the accumulation of radioisotopes in plankton is a function of temperature.

The levels of radioisotopes in plankton vary with time after the release of the isotopes, due to physical decay. Seymour (1959) stated that the fission products (mainly Ce-144) contributed 30 per cent of the activity in the plankton in the Pacific and 70 per cent was due to non-fission radioactive isotopes, mainly Zn-65, Co-57, -58, -60, Fe-55 and traces of Mn-54. Compared with fish, plankton had more radioactive Co and less Fe. Radioactive tungsten (W-185) has also been found in plankton.

4.4 Benthos

Benthic animals are those who spend most or all of their life on the bottom substrata. Some of them have commercial importance (oysters, lobsters, shrimps etc.) and most of them are consumed by demersal fish as food. These animals can take up radioactive isotopes by: (a) food, (b) direct absorption from the sea water, and (c) by contact with

bottom substrata. The levels of uptake of radioactive isotopes vary according to feeding habits of benthos. The benthonic organisms can be divided by feeding habits into: (a) filter feeders (filtering sea water and mud suspension); (b) detritus feeders (collecting organic particles actively or passing mud through the digestive tract); and (c) "hunters" (eating other benthos animals). Some of them, (e.g. shrimps) get part of their food from the water mass, as they make active feeding migrations into the water above. Also considerable seasonal migrations of vagile benthic animals along the bottom may occur (e.g. into deep water during the winter and back to shallow water during the summer).

Borough, Chipman and Rice (1957) found that oysters reached a steady state with radioactive food (containing strontium-89) in eight days and that the overall concentration factor was ca 2. Concentration of the radioactive elements however varied in different tissues of the shellfish. Soft tissues lost the activity quickly in non-active medium. Different elements however behaved differently. Cesium-137 in shellfish still increased continuously after 20 days. Chipman, Rice and Price (1959) found that zinc-65 was taken up by shellfish very rapidly and its concentration factor was ca 1000.

4.5 Fish

Because of the variations in the behaviour of radioactive isotopes in fish owing to the feeding and other living habits of pelagic and demersal fish, these should be dealt with separately.

Some small grown pelagic fish are filter feeders and use phyto- and zooplankton as food. Some species feed selectively on zooplankton organisms. Large pelagic fish usually feed on smaller pelagic fish. Depending on the feeding habits, the amounts of radioactive isotopes taken with food also decrease in the order described above. Some elements fed are rapidly excreted (e.g. Sr and Y, Borough *et al.*, 1956). Certain amounts of elements can be taken up by absorption and adsorption through skin, gills and digestive tract.

There is a selective transfer and accumulation of isotopes in different organs of fish, depending on their physiological function. Common elements of tissues and their radioactive isotopes (e.g. radioactive phosphorus) are distributed in all tissues more or less evenly. There also seems to be selectivity in uptake in closely related elements. Boroughs, Townsley and Hiatt (1956) found that the Sr/Ca ratio in fish is 1:40. This means that marine fish discriminate against strontium. However, vertebrate predators may also concentrate some elements (e.g. Cs-137) to higher levels than found in their prey (Pendleton and Hanson, 1958).

The rate of uptake is usually greater by younger species than by older ones and greater during the feeding season (spring) than during the rest of the year.

Demersal fish (e.g. plaice, rays etc.) spend part of their life on the bottom and feed partly on benthonic animals. However, they can get part of their food from the water mass as they usually make diurnal "up and down" migrations. Therefore, the ways and rates of uptake of radioactive isotopes of demersal fish depend greatly on their living and feeding habits (i.e. how much time they spend in contact with the bottom substrata and how great a proportion of food is taken from the bottom). Some demersal species are rather stationary (e.g. plaice) and some make considerable migrations. Pelagic as well as demersal fish usually have both diurnal migrations within depth and large seasonal migrations between spawning and feeding grounds. These migrations vary by species and by locality by the same species. Therefore, all the migratory habits must be ascertained in all prospective localities of disposal of radioactive wastes.

Some information on the behaviour of radioactive isotopes in fish is available. Chipman, Rice and Price (1959) found that zinc-65 was rapidly taken up by fish through gut to kidney, liver and other organs. Accumulation took place in bone, integument and muscle tissues. When resuspended into non-active medium there was an immediate loss of most of the radiozinc. However, a small percentage remained with only very slight loss over periods of many days. Similar conclusions on the loss of radioactive isotopes were made by Borough, Chipman and Rice (1957). They found that most radioactive elements are lost quickly and after 24 hours, less than 10 per cent is left in the fish body, which is usually found in order of decreasing concentration, in alimentary tract, liver, skin, bones and muscles. The percentage of isotopes retained depends on the element, its place of accumulation, feeding habits and size of fish. Krumholz, Goldberg and Borough (1957) found that less than 5 per cent of the strontium-90, given with a single feeding to mackerel, was retained in the body after 48 hours. Much of the retained isotope was incorporated in bones. Of the strontium-89 fed to tunas, only 1 to 2 per cent remained in the body after 24 hours.

Welander (1957) found that the rate of decline was greatest during the first 100 days (90 per cent) after uptake and that the biological decline of radioactivity was essentially similar in all species. Existing small differences were caused by feeding habits and uptake and retention of short-lived isotopes. Decay in omnivores was more rapid than in carnivores.

4.6 Sea birds

Sea birds can probably take up the radioactive isotopes by food. No data are available on this subject. It is assumed however that those birds feeding on intertidal animals during low tides, close to the disposal sites will take up more radioactive isotopes than those birds which feed on pelagic fish.

TABLE 1

AVERAGE CONTENT OF SOME ELEMENTS IN MARINE BIOSPHERE (IN mg PER g OF BIOMASS) AND THE CONCENTRATION RATIOS
(Rough estimates from various sources)

Compound or element	Marine algae	Phyto-plankton	Zoo-plankton	Fish	In sea water (mg per kg of sea water)	Range of concentration ratios (kg of sea water/kg of biomass) /The most common values are underlined/
(Water content)	80%	92%	80%	75%		
Nitrogen	5	4.3	20	30	0-0.5 (av. 0.1)	1:50,000-1:300.000
Sodium	10		3	1	10561	10:1-1:1
Potassium	8		3	3	380	<u>1:10</u>-1:20
Cesium	$5x10^{-6}$		$2x10^{-5}$	$2x10^{-5}$	0.0005-0.002	1:1-1:10
Calcium	4		(1)	0.4	400	1:1-1:10
Strontium	0.15		0.07	0.007	7	1:1-1:20
Magnesium			0.4	0.3	1272	4:1-3:1
Phosphorus	(2.5)	0.55	1.6	1.8	0-0.88(av.0.02)	1:10,000-1:90,000
Sulphur			4	2	884	1:3-1:5
Iron	0.1	0.1	0.05	0.01	av.0.01	1:1,000-<u>1:10,000</u>
Nickel	0.001	0.001		0.0002	0.0002	1:100-1:500
Cobalt					0.0002	1:190-1:10,000
Copper	(0.005)		0.006	0.01	0.002	1:1,000-1:5,000
Zinc	(0.01)		0.1	0.025	0.005	1:1,000-<u>1:20,000</u>
Radium	$2x10^{-11}$		$1x10^{-12}$	$1x10^{-12}$	$2-3x10^{-10}$	1:1-1:100
Cadmium	0.0006				0.00006	1:10,000
Iodine	0.01-1		0.002	0.00015	0.05	1:3-<u>1:20,000</u>
Manganese	0.002-0.04	0.0001	0.002		0.004	1:25-1:10,000
Aluminium	0.01				0.5	1:20
Titanium	0.001				0.001	1:100

REFERENCES

Aten, A.H.W., Radioactivity in marine organisms. II U.N.Int.Conf.
1958 Peac.Uses Atom.Energ., A/Conf.15/P/547.

Boroughs, H.A., S.J. Townsley and R.W. Hiatt, The metabolism of
1956 radionuclides by marine organisms. I. The uptake, accumulation and loss of strontium-89 by fishes. Biol. Bull. Woods Hole, 111:336-351. Wat.Pollut.Abstr., 30(5): 177, (1957).

Boroughs, H.A., S.J. Townsley and R.W. Hiatt, The metabolism of
1956 radionuclides by marine organisms. II. The uptake, accumulation and loss of yttrium-91 by marine fish, and the importance of short-lived radionuclides in the sea. Biol. Bull. Woods Hole, 111 (3): 352-357. Wat. Pollut.Abstr., 30(5):177

_____ The metabolism of radionuclides by marine organisms.
1957 III. The uptake of calcium-45 in solution by marine fish. Limnol.Oceanogr., 2(1):28-32

Boroughs, H.A., W.A. Chipman and T.R. Rice, Laboratory experiments
1957 on the uptake, accumulation and loss of radionuclides by marine organisms. Publ.nat.Acad.Sci., Washington, D.C. (551):80-87

Boroughs, H.A. and S.J. Townsley and W. Ego, The accumulation of
1958 Y^{90} from an equilibrium mixture of $Sr^{90}Y^{90}$ by Artemia salina L. Limnol. Oceanogr., 3(4):413-417.

Chipman, W.A., T.R. Rice and T.J. Price, Uptake and accumulation of
1958 radioactive zinc by marine plankton, fish and shellfish. U.S. Fish and Wildlife Service. Fishery Bull. 135 58: 279-292

Coopey, R.W., Radioactive plankton from the Columbia river. AEC
1951 Gov. Doc.H.W.-20668 (March 29, 1951). Nuc.Sci.Abst., 6:513, (1952)

Donaldson, L.R., Biological cycles of fission products in aquatic
1955 systems as studied at the Pacific atolls of Bikini and Eniwetok. Int. Conf.Peaceful Uses Atomic Energy. A/CONF.8/P/282 Abstract (USA).

Donaldson, L.R., R.F. Foster, Effects of radiation on aquatic
1957 organisms. Publ.nat.Acad.Sci., Washington, D.C., (551):96-102

Donaldson, L.R., A.H. Seymour, E.E.Held, N.O. Hines, F.G. Lowman,
1956 P.R. Olson and A.D. Welander. Survey of radioactivity in the sea near Bikini and Eniwetok atolls, June 11-21 1956 (mimeographed) Univ.of Wash. Fisheries Lab.

Folsom, T.R., J.H. Harley, Comparison of some natural radiations
1957 received by selected organisms. Publ.nat.Acad.Sci., Washington, D.C. 551: 28-33

Folsom, T.R., S. Hori, Artificial and natural radioactivities in
M.S. marine biota and sediments of the Eastern Pacific

Foster, R.F., and J.J. Davis. The accumulation of radioactive
1955 substances in aquatic forms. Int.Conf. on the Peaceful Uses of Atomic Energy, June 1955. Wat.Pollut.Abstr., 29(4)Abs.802.

Gong, J.K., W.H. Chipman, H.V. Weiss and S.N. Cohn. Uptake of fission
1957 products and neutron-induced radionuclides by the clam. Proc. Soc.exp.biol.Med., 95:451-4, Chem.Abstr. 51(18): 14147

Harley, I.F. [Ed.], Operation Troll. U.S. Atomic Energy Comm., N.Y.
1956 Operation Office. V+ 37 p.

Hiatt, R.W. et al Radioisotope uptake in marine organisms with
1955 special reference to the passage of such isotopes as are liberated from atomic weapons through food chains leading to organisms utilized as food by man. Hawaii Marine Lab. USAEC doc. AECU-3079.

Hiyama, Y. Biological cycle of fission products considered from view-
1955 point of contamination of marine organisms. Int. Conf. Peaceful Uses of Atomic Energy. A/CONF.8/P/1052. (Mimeo.)

Hiyama, Y. and R. Ichikawa, Uptake of strontium by marine fish from
1957 the environment. Rec.oceanogr.Wks.Jap. 3(1):78-84

Ketchum, B.H. and V.T. Bowen, Biological factors determining the dis-
1958 tribution of radioisotopes in the sea. 2nd Int. Conf.Peac. Uses Atom.Energ., A/Conf.15/P/402: 11 p.

Krumholz, L.A., E.D. Goldberg and H. Boroughs, Ecological factors
1957 involved in the uptake, accumulation and loss of radionuclides by aquatic organisms. Publ.nat.Acad.Sci., Washington, D.C., (551):69-79

MacRobbie, E.A.C. and J. Dainty, Sodium and potassium distribution
1958 and transport in the seaweed Rhodymenia palmata L. Grev. Physiologia Plantarum, 11(4):782-801.

Morgan, F. Uptake of radioactivity by plaice. The Challenger Society
1956 3(8):21

Pendleton, R.C. and W.C. Hanson, Absorption of cesium-137 by components
1958 of an aquatic community. 2nd U.N.Int.Conf.Peace.Uses Atom. Energ., A/Conf.15/P/392; 10 p.

Rice, T.R. and V.M. Willis, Uptake, accumulation and loss of radio-
1959 active cerium-144 by marine planktonic algae. Limnol. and Oceanogr. 4(3):277-290

Saito, K. and M. Samashima, Studies on the contamination of marine
1956 algae by fission products. Mem.Fac.Fish,Kagoshima Univ., 5:196-204

Seymour, A.H., E.E. Held, P.G. Lowman, J.R. Donaldson and D.J. South,
1957 Survey of radioactivity in the sea and in pelagic marine life west of the Marshall Islands, September 1-20, 1956 (Mimeo.) Univ. of Wash., Fisheries Lab.

Shirai, K., M. Saiki and S. Ohno, Studies on the radioelement in the
1957 contaminating radioactive fish. III. On shipjacks caught at the Pacific Ocean in 1956. (Part 2). On the presence of Cd^{113m} Bull.Ja.Soc.sci.Fish., 22:651-3

Slater, J.V., Radiocobalt accumulation in Tetrahymena, Biol.Bull.Wood's
1957 $H_o$le, 112(3):390-9

Takada, K. and J. Nishimoto, The behaviour of fission product for the
1956 fish meat. Mem.Pac.Fish., Kagoshima Univ., 5:190-195

Tanaka, T. On the contamination of marine algae by fission product.
1956 Mem.Pac.Fish., Kagoshima Univ., 5:205-209

Tozawa, H., Y. Tokue and K. Amano, Studies on the radioactivity in
1957 certain pelagic fish - V. Confirmation and determination of radioactive elements in contaminated fishes caught in 1956 (Part 1) Bull.Jap.Soc.sci.Fish., 23(6):335-41

Weiss, H.V., and W.H. Chipman, Biological concentration by killer
1957 clams of cobalt-60 from radioactive fallout. Science 125(3250):695

Welander, A., Radioactivity in the reef fishes of Belle Island,
1957 Eniwetok Atoll, April 1954 to November 1955. Univ. of Wash. Fisheries Lab.

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FAO Fisheries Biology Technical Paper	FB/T(No.)

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CART Synopses of information concerning the living aquatic resources of certain countries and regions

SAST Synopses of data concerning certain species and fish stocks

MAST Methods and subjects synopses

OT Oceanographic synopses

IT Synopses of data for inland waters

Certain of the Technical Papers are also within special series, thus -

RE Indexed lists of names and addresses of experts drawn from the Register of Experts maintained by Biology Branch

CB Papers relating to the Current Bibliography for Aquatic Sciences and Fisheries and fisheries biological documentation and intelligence services.

Numbers or phrases following the series symbols are for classifying the document, using the codes of the indexes to the "Current Bibliography for Aquatic Sciences and Fisheries".

Some documents may carry other identification numbers, if for example, they have been contributed to a meeting for which papers have been marked according to another system; in requesting copies of documents it is sufficient, however, to quote the "FB" number given at the top right-hand corner of the cover sheet.